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Evaluation of Friction Stir Processing for fabrication of composites in the context of Industry 4.0: A Bibliometric Review

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Evaluation of Friction Stir Processing for fabrication of composites in the context of Industry 4.0: A Bibliometric Review

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Abstract

Aluminum alloys having good strength to weight ratio and resistance to corrosion have a wide range of applications in aerospace, automobiles, military, sports and many other applications. In order to enhance the hardness and wear resistance of the surface without compromising the bulk properties, aluminum matrix based surface composites fabricated with various reinforcements on the surface are now a days being utilized widely as new generation materials. In the manufacturing of metal surface hybrid composites (precisely of light weight alloys like- Al, Mg, etc.), the friction stir processing is a promising new solid state processing technique which is versatile enough to incorporate controlled uniform distribution of the reinforcements into the matrix for reduced defects and improved properties at the surface. The objective of this bibliometric review is to understand the scope of Industry 4.0 applications in the condition monitoring and evaluation of friction stir processing for fabrication of surface hybrid composites based on the existing literature. In order to analyze the available literature, a total of 1027 published documents have been studied using scopus database. Based on the published documents, research is focused on the analysis based on yearly published documents, types of documents, source titles, keywords searched, affiliations of authors, funding sponsors, countries related, source types, languages of publications, etc.

Keywords: Bibliometric review; friction stir processing; aluminium surface composites; condition monitoring; Industry 4.0.

Introduction

The fastening process is one of the most common and integral part of any product manufacturing process. Fastening can be temporary using nut and bolt, rivets etc., or can be permanent such as welding, soldering and brazing processes. The performance and reliability of any product manufactured is largely dependent on these joining techniques and methods. Research and development in the area of permanent joining is in a continuous progression with new innovations and developments and is carried out with the main aim of increasing the joint performance with minimum effect on surface characteristics of the joined part.

The friction based joining methods, also termed as “Green welding processes”, have recently gained interest among the researchers worldwide since they do not require or produce any

environmentally hazardous chemicals, gases, etc. The Friction Stir Welding (FSW) process is such a process which is generally used to join two metallic parts utilizing friction which was first attempted in 1991 in UK [(Hsu, Kao, and Ho 2005)] at The Welding Institute using aluminum alloys. The friction stir processing (FSP) was developed based on same technique as friction stir welding with a purpose to modify the surface of the work-pieces. This can be performed on any Vertical Milling Machine and utilizes the same tool as that in friction stir welding to refine the microstructure of the surface of a metal rather than joining two metal pieces as in FSW. In FSP, a non-consumable tool consisting of a shoulder with a small diameter pin protruding at its tip is mounted on the machine and rotates on its axis. This pin is inserted inside the material and the tool shoulder rubs over the surface with the aid of a vertical axial load in the machine tool. Since the tool is rotating and the work-piece is stationary, the friction due to rubbing of the shoulder and the metal surface generates a considerable amount of heat. When this heat produced reaches the recrystallization temperature of the work-piece, the material becomes plastically soft and the pin stirs this softened material around it from front to back as the tool is traversed forward in its path. Hence the microstructure of the material, specially in the volume of pin traverse (called stir zone), gets completely refined improving the properties. The rise in temperature can easily deform the metals plastically, and the traverse movement of the tool makes the metal to get extruded around the tool before being forged by the vertically downward force imparted by the machine tool [(Seidel and Reynolds 2001)(Ratanathavorn and Melander 2015)(Charit and Mishra 2003)]. In addition to welding, the principles of FSW has been applied in the surface modification techniques also. Friction stir alloying (FSA) and friction stir processing (FSP) are few examples of it and have attracted the research community to explore more possibilities [(Asgharzadeh, Faraghi, and Kim 2017)]. Since this method involves refining of the microstructure without any melting of the material surface (avoiding defects caused during solidification) and there is a possibility to add other particles (reinforcements) into the surface imparting their properties, it is highly recommended to use friction stir processing for manufacture of surface nanocomposite materials.

Aluminium based composites have a wide range of engineering applications such as in aerospace industry, automobile sector, electronics, and packaging industry since these have superior strength to weight ratio (Tamboli et al. 2019). Some researchers applied FSP in order to manufacture aluminium matrix surface composites using multiple ceramic reinforcements (Sharma, Sharma, and Paul 2020). Mishra et. al. [(Charit and Mishra 2003)] carried out research based of the principles of FSW and first developed the FSP process with main objective of modifying the microstructural properties of the materials. Many such experiments were carried out following the FSP procedure and it was shown that FSP can effectively be used for many material property enhancement such as to modify the microstructure of aluminium and magnesium alloys into ultrafine grain structure [(Lee, Yeon, and Jung 2003)(Kwon, Shigematsu, and Saito 2003)(Rhodes et al. 2003)(Su, Nelson, and Sterling 2005)(Chang, Lee, and Huang 2004)], to impart super-plasticity in light weight alloys [(Ma, Mishra, and Mahoney 2002)(Charit and Mishra 2003)] and to refine the microstructure of existing nanocomposite materials based on aluminium alloys [(Berbon et al. 2001)].

For any manufacturing process to be commercially competitive in terms of product quality and cost, it needs to be Industry 4.0 compatible. The fourth industrial revolution also known as Industry 4.0 is an advancement from the third industrial revolution by the integration of cutting edge technologies such as Artificial Intelligence, Machine Learning, Internet of Things, 3D

Printers and scanners, nanotechnology, cloud computing in the manufacturing industries. For FSP to be Industry 4.0 ready, it needs to be more autonomous and equipped with adequate sensors for collection of useful information such as force, temperature during the process, vibration data, etc. in addition to the data pertaining to the health and condition of the FSP machine. The integration of sensors for data collection and condition monitoring and process monitoring during the friction stir processing, will help in controlling and predicting the process anomaly and there by controlling the quality for the finished products. This aspect of the friction stir processing is rarely studied by the researches.

Condition monitoring and Anomalies detection in Friction Stir Processing in the context of Industry 4.0

Pertaining to the challenges in an industry to design an infrastructure capable of collecting, managing and processing of the data acquired from different heterogeneous sensors, Fabrizio De Vita et al. [(De Vita, Bruneo, and Das 2020)] implemented an anomaly prediction algorithm that employed fusion of sensors data in order to estimate the working conditions of an industry. The erroneous and abnormal readings of sensors (in time series form) and hence the working conditions of the network, were predicted by an anomaly detection model proposed, that was based on edge computing and the faulty data was detected by an improved confidence interval obtained [(Yin, Li, and Yin 2020)]. Another study of investigating the fault in sensor data proposed, was established by clustering of correlated data [(Yoo 2020)], where data relationship was recognized, a clustering model was generated and the fault index was calculated based on random distances. An approach of fault detection in the readings of sensors in a surveillance network [(Marzat, Piet-Lahanier, and Bertrand 2018)] was proposed to study the characteristics of anomalies in sensor networks and the techniques associated for correction with the help of a case study in a sensor network area considering events in the form of binary measurements. An attempt to detect the fault in measuring energy data [(Hu et al. 2019)] also proposed a methodological and statistical analysis that considers existing sensor data, identifies data from expert knowledge, integrates the domain knowledge (creation of virtual sensors) and selects the data using appropriate machine learning algorithms. A recent attempt by Francesco Cauteruccio et al. [(Cauteruccio et al. 2021)] has been made to investigate the anomalies detection and classification in multiple IoT frameworks focusing various parameters affecting good network connection and efficient exchange of data from the sensors. These works motivate to develop and apply an online monitoring and anomalies detection model that leads to an improved microstructure in work-piece and reduced tool wear and hence improved tool life in friction stir processing. An implemention of IIoT framework is shown in Figure 1.

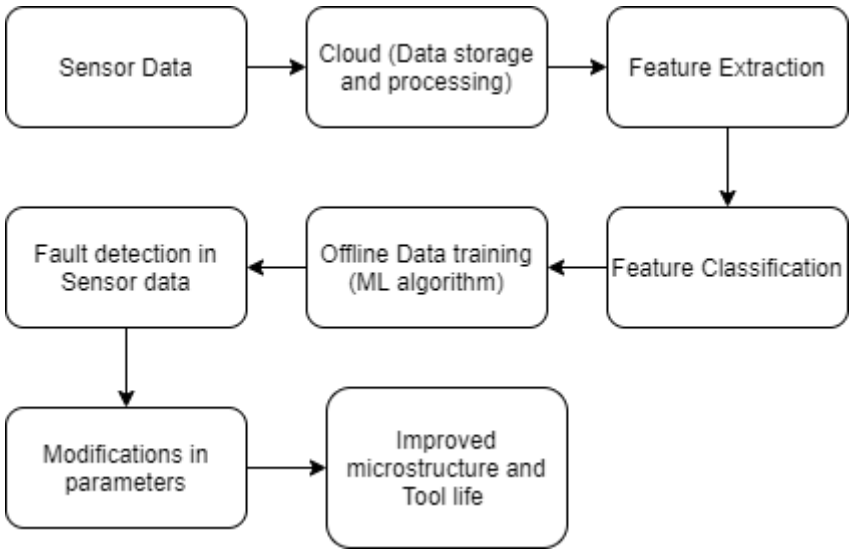

Figure 1: Condition Monitoring Mehodology in FSP

2. Bibliometric Analysis

In this bibliometric analysis, a quantitative analysis of the research data is conducted based on a total of 1027 published documents and qualitative study based on related citations. This survey aims to explore the year wise publication data, document types, language-wise distribution of documents, funding sponsors, authors contributions, affiliations, document wise citations, source title, etc., which helps to understand the advancement trend particular research area. To perform this bibliometric analysis, the Scopus database is used to achieve this paper's objective as Scopus is having larger peered reviewed theoretical and reference databases in areas of Engineering and Technology, Science, etc. This bibliometric paper helps to analyze the documents from different sources such as journals, conferences, books, notes, etc. which helps identify the research problems, research gaps, and future scope in a specific field of research.

2.1 Keywords Analysis

Scopus database is used for the selection of the keywords string. A large number of documents are available on the Scopus database for key terms search during the keywords string selection. Different strings with varying key have been considered and then the keyword string to be analysed for this bibliometric study was finalized to obtain more refined results.

Here, the keywords are classified into three groups: master keyword, primary keyword using AND operator and secondary keywords using OR operator based on the search string. The details of the keywords are given in Table 1.

Table 1: Master, Primary, and Secondary keywords
Source: https://www.scopus.com/ (accessed on January 6, 2021)

Master keyword	“Friction Stir Processing”
Primary keyword	“composites”

Secondary keywords	“Machine learning”, “Industry 4.0”, “Condition monitoring”, “Sensor data”, “Anomaly detection”.

2.1.1 Publications trend Analysis:

Table 2 shows the year-wise publication trend of published documents in the selected search string field. For finding publications, the trend duration of years from 2001 to 2021 is considered. From the publications trend, it is found that the research in friction stir processing emerged as a continuously increasing trend in research in the past years upto 2019 and then a slight decrease in number since 2020. This brings light to the need of research in friction stir processing for better tool life, microstructure obtained and improved quality of finished surfaces.

Table 2: Analysis of year-wise publication trend
Source: https://www.scopus.com/ (accessed on January 6, 2021)

Year	No. of Publications	Year	No. of Publications
2021	6	2010	24
2020	164	2009	16
2019	196	2008	7
2018	137	2007	8
2017	92	2006	11
2016	78	2005	2
2015	84	2003	3
2014	58	2001	1
2013	63		
2012	35		
2011	42		

Figure 1 shows the graphical representation of table 2, showing the trend in last ten years of publications in the research in friction stir processing. In the year 2019, the maximum number of around 196 documents were published in this field.

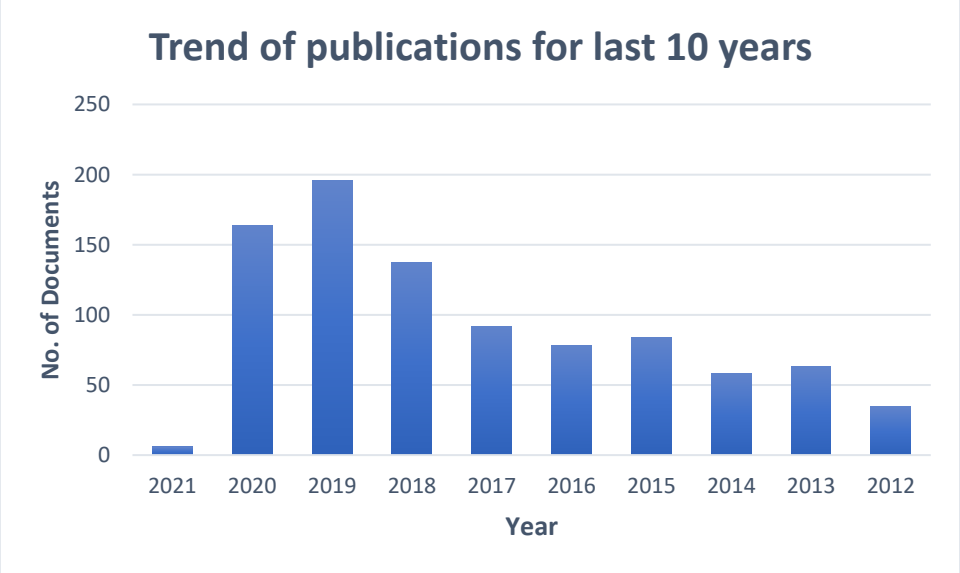

Figure 1: Year-wise trend of publication for the last 10 Years.
Source: https://www.scopus.com/ (accessed on January 6, 2021)

2.1.2 Country wise publication trend analysis:

Table 3 shows the number of documents published in the selected search string field (Scopus database). The maximum number of documents are published in the India (381) followed by Iran (204) and China (180). India has the highest number documents published in research in this field. So it has a good future scope of research in this area. Figure 2 indicates the geographical region-wise location clusters in the world map created by using Microsoft excel file.

Table 3: Country-wise number of documents published
Source: https://www.scopus.com/ (accessed on January 6, 2021)

Name of Country	No. of documents	Name of country	No. of documents
India	381	Nigeria	14
Iran	204	Malaysia	13
China	180	Turkey	13
United States	58	Belgium	12
South Africa	46	Pakistan	12
Japan	30	Australia	11
Taiwan	28	Slovakia	11
Canada	26	Singapore	9
Egypt	23	Spain	9
Saudi Arabia	19	United Kingdom	9
France	17	Poland	8
South Korea	16	Portugal	8
Italy	14	Russian Federation	7

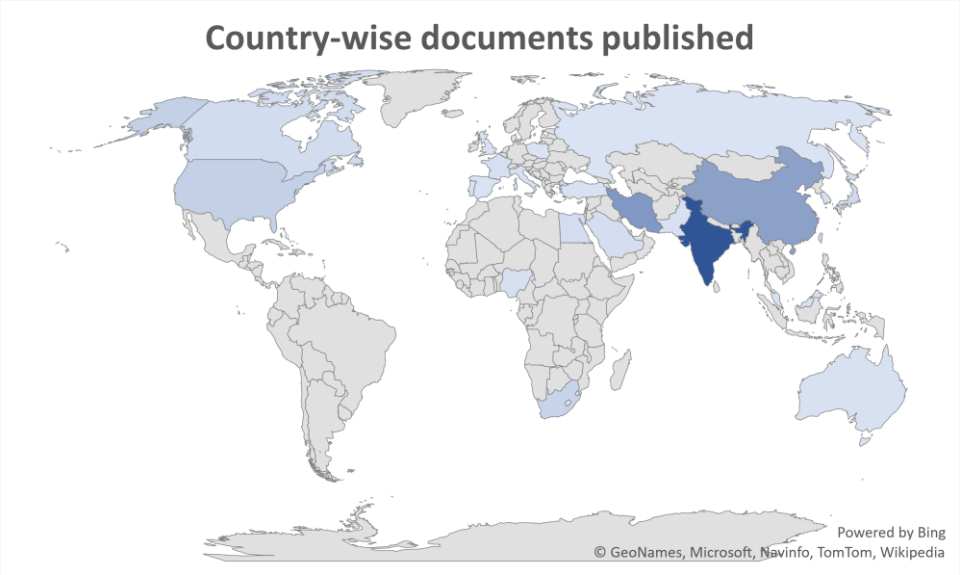

Figure 2: Country-wise locations of research related to Friction stir processing
Source: https://www.scopus.com/ (accessed on January 6, 2021)

2.1.3 Analysis by Subject Area

Figure 3 shows the top eight subject areas in the selected search string field. Most of the research is carried out in the Material science field, followed by in Engineering field. Approximately 41% of research related to this field is done in Material Science, followed by 34% research in the Engineering field, followed by 16% research in the field of Physics and Astronomy. This indicates that friction stir processing is having an important role in the field of Material science and Engineering fields. Another areas, such as Chemistry (3%), Computer science (2%), Chemical Energy (2%) and Business Management and Accounting (1%) are having less contribution of research in Friction stir processing.

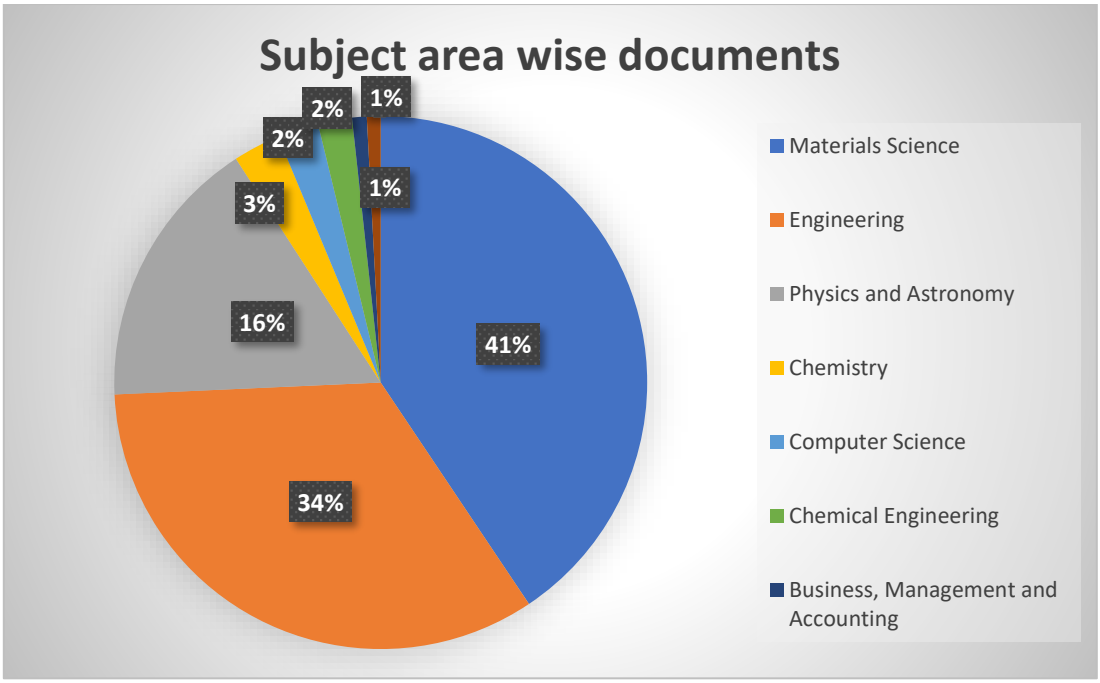

Figure 3: Top eight subject areas in friction stir processing
Source: https://www.scopus.com/ (accessed on January 6, 2021)

2.1.4 Document type-wise publication trend analysis:

Table 4 shows the analysis of the document-type wise list of documents published in different in Friction stir processing. From the table, it is found that the maximum number of papers are published in article type followed by conference paper type.

Table 4: Document type-wise number of publications
Source: https://www.scopus.com/ (accessed on January 6, 2021)

Document Type	Publications	Document Type	Publications
Article	737	Book	3
Conference Paper	195	Erratum	3
Review	33	Data Paper	2
Conference Review	26	Letter	1
Book Chapter	24	Note	1

Figure 4 shows the percentage-wise graphical representation of the number of documents published in different types of documents. Articles and Conference paper contribute approximately 72% and 19% documents, respectively.

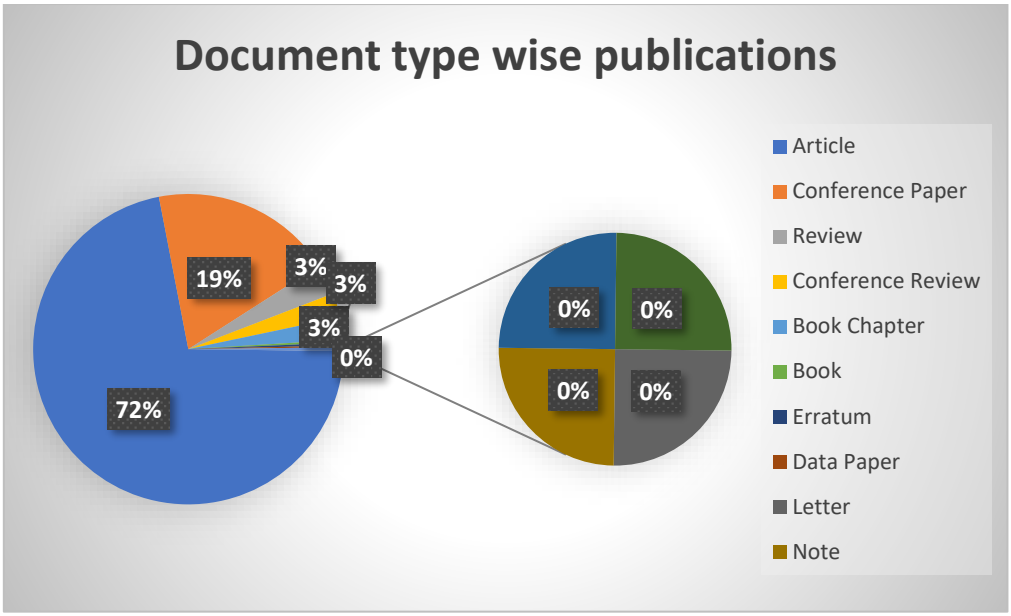

Figure 4: Document type-wise publications trend
Source: https://www.scopus.com/ (accessed on January 6, 2021)

2.1.5 Authors based analysis:

Figure 5 shows the number of publications based graphical representation of ten most significant authors whose studies are quite large in this field. Dinaharan, I. has a maximum number of publications (41), followed by Akinlabi, E.T. (28) in this field. Other authors, like Maheshwari, S. (24), Murugan, N. (22), Siddiquee, A.N. (22), Ma, Z.Y. (21), Ke, L (20), Kashani-Bozorg, S.F. (18), Asadi, P. (17) and Mahoney, Shen, Y. (17) have significant work in this research field.

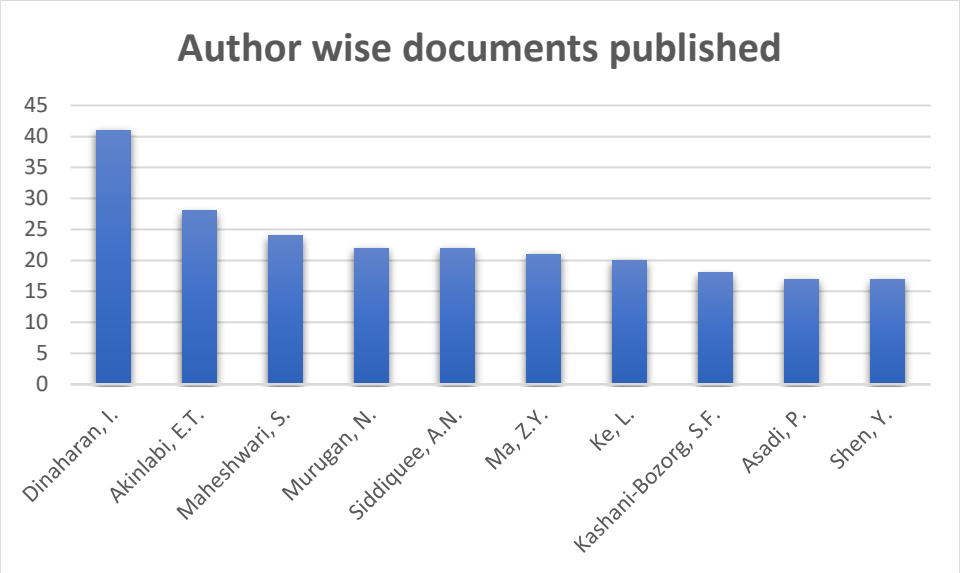

Figure 5: The author wise publications trend
Source: https://www.scopus.com/ (accessed on January 6, 2021)

2.1.6 Affiliation Institutes based analysis:

Figure 6 shows the best 10 affiliation institutes or research centers or organizations in this area. University of Tehran has maximum number of affiliations (69). The University of Johannesburg (46), Coimbatore Institute of Technology (31), Nanchang Hangkong University (31), Anna University (29), Indian Institute of Technology Madras (25), Chinese Academy of Sciences (24), etc. have significant number of affiliations in this area.

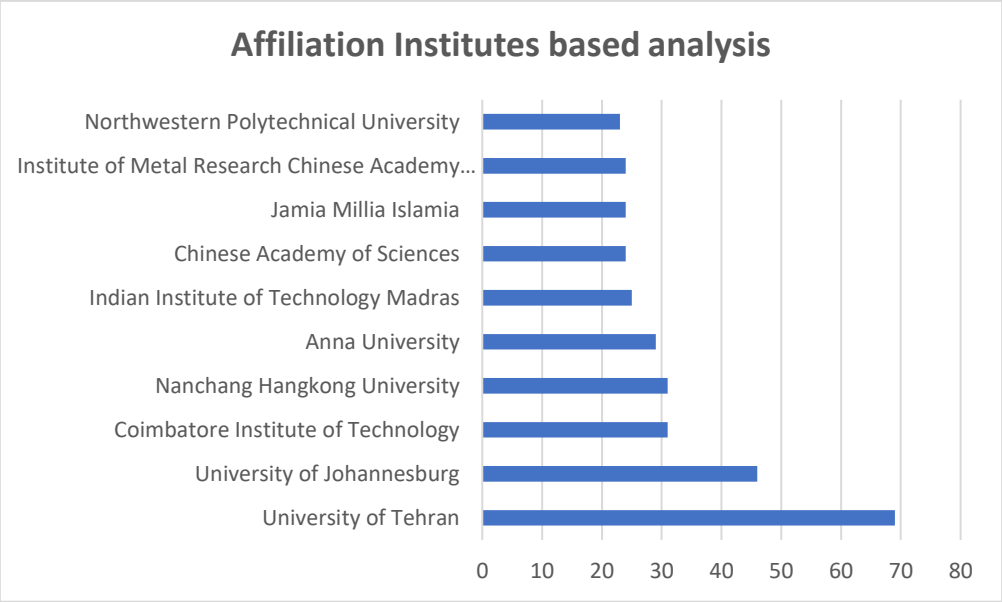

Figure 6: Top 10 Affiliation-wise institutes or research centres
Source: https://www.scopus.com/ (accessed on January 6, 2021)

2.1.7 Funding Sponsors based analysis

Figure 7 shows the top ten funding sponsors in the field of the Friction stir processing. The majority and surprising fundings are sponsored by the "National Natural Science Foundation of China" with 71 publications. Other fundings are supported by "National Basic Research Program of China" and "Naval Research Board" with 14 publications each.

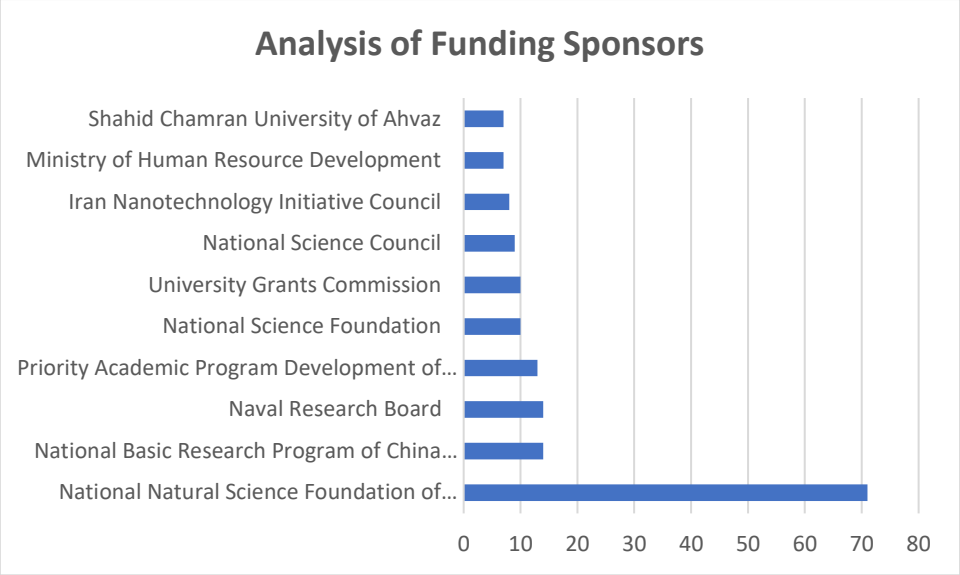

Figure 7: Top Ten funding sponsors
Source: https://www.scopus.com/ (accessed on January 6, 2021)

2.1.8 Language based analysis

From language trend analysis, it is found that approximately 971 documents are published in the English language. Considerably fewer papers are published in other languages, such as 47 documents in Chinese, 9 documents are in Japanese. Figure 8 shows the percentage contribution of languages in the available record. Most of the documents are restricted to the English language only.

Figure 8: Language wise trend analysis
Source: https://www.scopus.com/ (accessed on January 6, 2021)

2.1.9 Source title based trend analysis:

Figure 9 shows the top ten source title analysis. From the study, it is observed that Material Science and Engineering have a maximum 55 number of documents. Another source titles like Materials Today Proceedings (49), Materials Research Express (40), Journal Of Alloys And Compounds (33) and Materials And Design (26) have significant number of publications in this area.

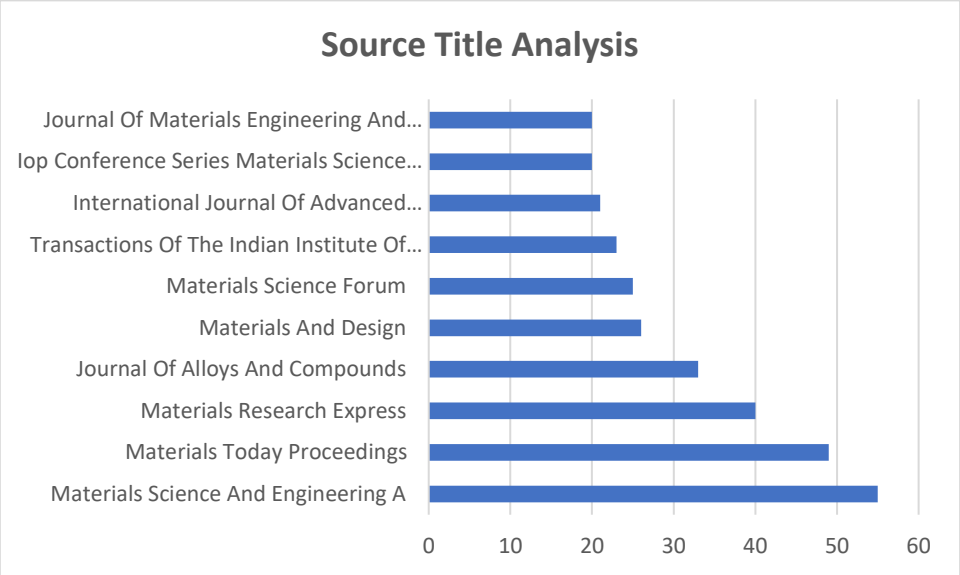

Figure 9: Analysis based on Source title.
Source: https://www.scopus.com/ (accessed on January 6, 2021)

2.1.10 Citations based analysis:

Citation wise analysis trend is shown in figure 10. In the last seven years, the citation count is increased significantly. The graph shows the continuous increasing trend in the past recent years. In the year 2020 maximum of 4370 times, friction stir processing-related documents are cited.

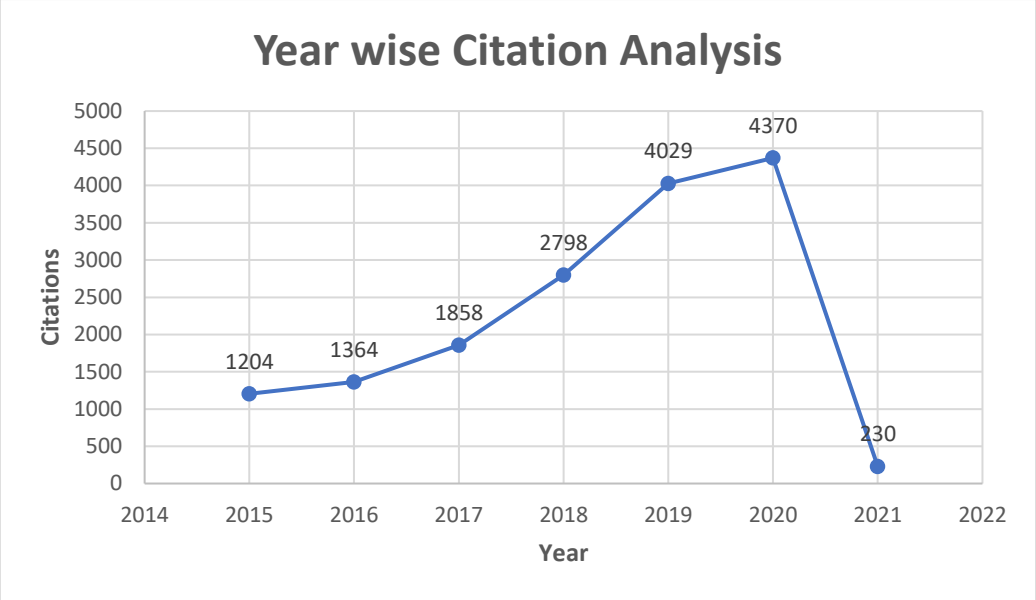

Figure 10: Last seven years of citations.
Source: https://www.scopus.com/ (accessed on January 6, 2021)

Table 5 shows the highest ten documents in the field of Friction stir processing based on the Scopus database. Publications having the title “Friction stir processing: A novel technique for fabrication of surface composite” has the maximum number of 698 citations from the year 2015 to 2020.

Table 5: An analysis of highest ten publication based on citations
Source: https://www.scopus.com/ (accessed on January 6, 2021)

S. No.	Document Title	Authors	Journal Title	2015 1204	2016 1364	2017 1858	2018 2798	2019 4029	2020 4370	Total 18629
1	Friction stir processing: A novel technique for fabrication of surface composite	Mishra R.S., Ma Z.Y., Charit I.	Materials Science and Engineering A	56	53	52	83	94	76	698
2	Friction stir processing technology: A review	Ma Z.Y.	Metallurgical and Materials Transactions A: Physical Metallurgy and Materials Science	58	59	58	80	89	78	683
3	Al-Al_3Ti nanocomposites produced in situ by friction stir processing	Hsu C.J., Chang C.Y., Kao P.W., Ho N.J., Chang C.P.	Acta Materialia	36	27	33	36	32	35	318
4	MWCNTs/AZ31 surface composites fabricated by friction stir processing	Morisada Y., Fujii H., Nagaoka T., Fukusumi M.	Materials Science and Engineering A	27	24	18	32	14	20	294
5	Microstructures and mechanical properties of Al/Al_2O_3 surface nano-composite layer produced by friction stir processing	Shafiei-Zarghani A., Kashani-Bozorg S.F., Zarei-Hanzaki A.	Materials Science and Engineering A	25	28	29	34	36	24	265
6	Mg based nano-composites fabricated by friction stir processing	Lee C.J., Huang J.C., Hsieh P.J.	Scripta Materialia	16	25	17	27	17	19	261
7	Surface composites by friction stir processing: A review	Sharma V., Prakash U., Kumar B.V.M.	Journal of Materials Processing Technology	1	21	27	47	63	52	214

8	Review of tools for friction stir welding and processing	Zhang Y.N., Cao X., Larose S., Wanjara P.	Canadian Metallurgical Quarterly	11	18	20	47	45	39	198
9	Investigating effects of process parameters on microstructural and mechanical properties of Al5052/SiC metal matrix composite fabricated via friction stir processing	Dolatkhah A., Golbabaei P., Besharati Givi M.K., Molaiekiya F.	Materials and Design	20	25	33	33	39	19	191
10	Effect of rotational speed and probe profile on microstructure and hardness of AZ31/Al_2O_3 nanocomposites fabricated by friction stir processing	Azizieh M., Kokabi A.H., Abachi P.	Materials and Design	18	15	20	23	35	33	191

Citation Analysis using Gephi software

In Figure 11, a graph representing the citation data analysis performed on research articles considering two attributes i.e. source title and citation count, using a gephi software methodology, is shown. In this network or graph, a number of 1594 articles (as nodes) are studied which seem to be connected with each other by 1894 citations (as edges). Using a force atlas algorithm, it shows in the graph that the most important articles which are cited more can be seen in the middle and those which are cited less are represented in the periphery of the graph. In order to represent ranking of the articles, in-degree attribute is selected which shows the number of times an article is cited by other articles. The darker the colour of the nodes shown in the graph, the more cited is the article and light coloured nodes show lesser number of citations. The strength of the division of the network into different modules such as groups, clusters or communities of articles can be achieved here by creating partitions in the articles using modularity class attribute. Here different coloured clusters are shown with the related articles of same colour. Many other analysis also can be performed using gephi technology.

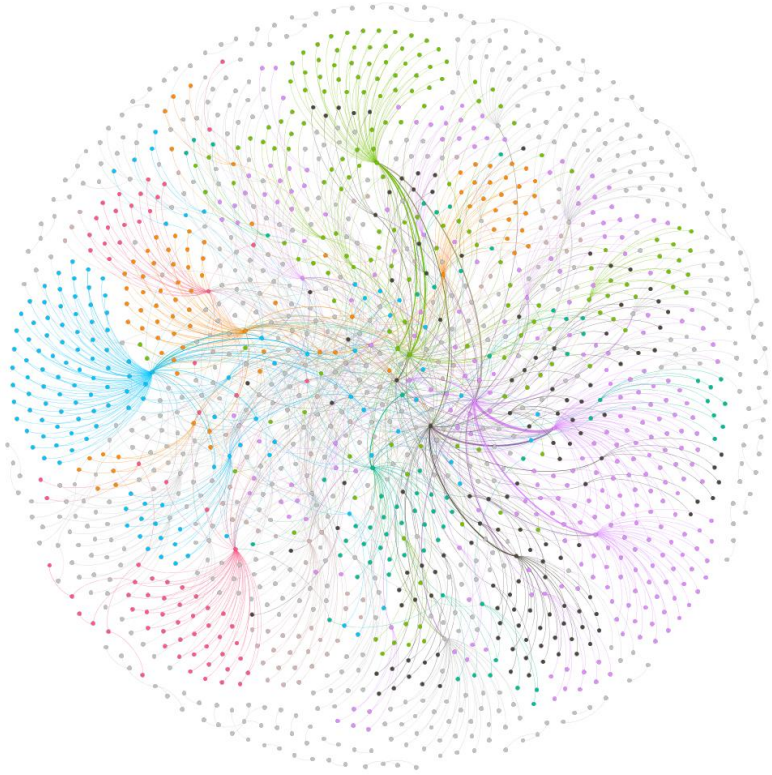

Figure 11: Network Analysis diagram based on keywords and source title.

Source: https://www.scopus.com/ (accessed on January 12, 2021)

Network Analysis

In this method, the relationship between two different attributes is represented through graphs using available softwares. In this analysis vosviewer software is used for network analysis using scopus data. Figure 12 represents the network analysis between source titles and index keywords based on co-occurrence. Here, the size of the graph indicates the level of incidence of the keywords. Wherever in the graph the distance between keywords is lesser, it shows stronger correlation between them and vice-versa. From the figure, it is shown that the keyword “friction stir processing” followed by “friction stir welding” have a stronger influence with other keywords. Same colored keywords represent the common clusters formed by these keywords. The minimum number of occurences of a keyword selected is 5. Hence only 534 keywords meet this threshold for the analysis and 9 clusters are formed.

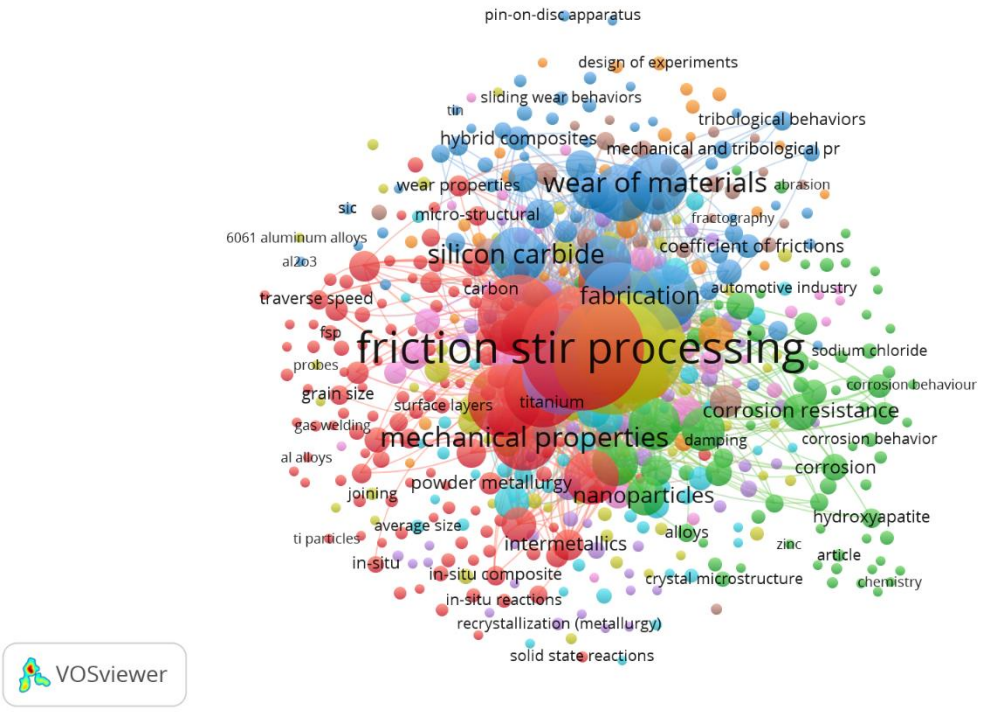

Figure 12: Network Analysis diagram based on keywords and source title.
Source: https://www.scopus.com/ (accessed on January 12, 2021)

Future work

In this paper, the bibliometric review is limited to only scopus database. Since it is subjected to various researches with each day, the data tends to change and hence is limited upto a certain time. The study can be widened if multiple databases like Web of Science, ScienceDirect, Google Scholar etc. are also considered for exploring more in the area of friction stir processing. This method can help in comparing different databases simultaneously and detect anomalies in real time for improved performance of this method. Several other combinations of attributes can be explored. Improvement in this bibliometric review can be done by including various other attribute analyses using VOSviewer and gephi software and even other techniques available that can elaborate different views to analyze the network.

Conclusion

In this paper, the bibliometric analysis in the Friction stir processing is represented based on the published documents which are extracted from the Scopus database. The study shows that Friction stir processing is Now-a days trending research area and is attracting attention of the researchers working in this area. Friction stir processing finds an important role and needs to be investigated and developed in the context of industry 4.0. This paper focuses on various maintenance methods available, and the challenges ahead for the investigation of friction stir processing. Countries like India, China, United States and Iran are the leading nations and have published a large number of published documents in the relevant research area. Approximately 66% and 26% of the papers are published in Articles and conferences. Of all the published documents, about 95% of documents are written in the English language. Major part of the research is carried out in the Material Science and Engineering domains. Mishra R.S. is the most predominant author in friction stir processing followed by followed by Ma, Z.Y., Fujii, H., Akinlabi, E.T., etc. Important two funding sponsors in this area, i.e. “National Natural Science Foundation of China” and “National Science Foundation” are from China. Citation analysis by Gephi software showed the citation of an article by other articles using modularity class attribute. VOSviewer is also explored for the network analysis between source titles and index keywords based on co-occurrence.

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